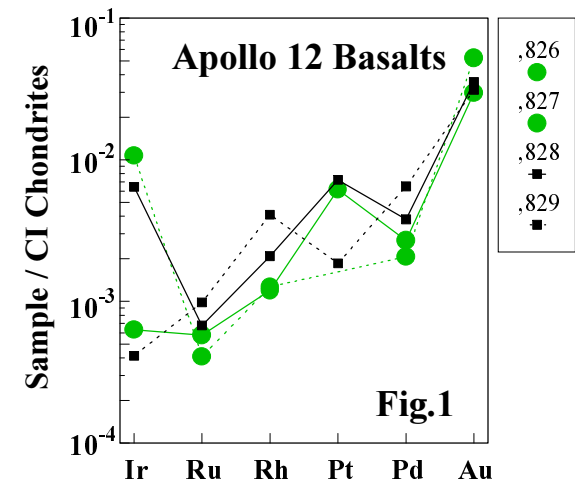


PLATINUM-GROUP ELEMENTS (PGEs) AND GOLD (Au) IN THE LUNAR REGOLITH: ROUTINE ANALYSIS BY ULTRASONIC NEBULIZATION-INDUCTIVELY COUPLED PLASMA-MASS SPECTROMETRY (USN-ICP-MS). G.A. Snyder, C.R. Neal*, J.A. O'Neill*, J. Jain*, and L.A Taylor, Planetary Geo- sciences Institute, Univ. of Tennessee, Knoxville, TN 37996-1410 (gasnyder@utk.edu); *Dept. of Civil Engineering and Geo- logical Sciences, University of Notre Dame, Notre Dame, IN 46556

Iridium (Ir) and Au have been used as the ultimate indi- cators of chemical pristinity of lunar materials. Determina- tion of these elements previously has been either by radio- chemical neutron activation (RNA) or by the less precise, and less sensitive, instrumental neutron activation (INA) method. We discuss a method of routine analysis of a suite of five PGEs and Au in lunar rocks using the USN-ICP-MS technique. Furthermore, we discuss the distribution of the PGE and Au in the regolith at the Apollo 12 landing site by looking at coarse-grained, presumably highlands materials, basalts, and impact melts. Impact melts have demonstrably higher abundances (3-5x) of Pd and Au and exhibit a uni- form positive slope from Ru --> Rh --> Pt --> Pd --> Au, when compared to both pristine highlands rocks and mare basalts. Pigeonite basalts have uniformly lower Ru, Rh, Pt, and Pd abundances than ilmenite basalts. Coarse-grained, presumably highlands rocks span a wide range, but generally have higher Ru, Rh, and Pt abundances than the mare basalts. PGE abundances and patterns may prove to be a new and important key to understanding mare basalt sources and an indicator of the degree of pristinity of lunar rocks.

METHOD OF ANALYSIS: USN-ICP-MS -- Warren and Wasson [1] suggested that pristine lunar rocks should contain $<3 \times 10^{-4}$ times chondritic abundances of Ir (i.e., <0.2 ppb). The analysis of PGEs (Ir, Ru, Rh, Pt, Pd) and Au abundances in pristine lunar samples is severely hampered by the fact that the Moon is relatively depleted in the highly siderophile PGEs and Au compared to the Earth [e.g., 2,3]. A method has been developed which employs USN-ICP-MS to quantify PGE and Au abundances in geological samples. *This method has measurable detection limits in the fem- togram/gram (ppq) range, with reagent blank levels either below detection limit or in the pg/g range (Table 1).*



This sample is dissolved on a hot plate using standard HF/HNO₃ procedures and is then placed in concentrated aqua regia in a pressure vessel at a temperature of 170°C for 48 hours. This stage ensures the complete dissolution of non-silicate phases (i.e., those where the PGEs and Au re- side). After drying and treatment with 12N HCl, the sample is brought up in 5% HCl and loaded on to a cation exchange column. The PGEs and Au form chloro-complexes and pass through the column immediately ($\geq 95\%$ recoverability is observed) leaving behind interfering elements. This method allows the PGEs and Au to be analyzed without dilution which would push the abundances below the detection limit.

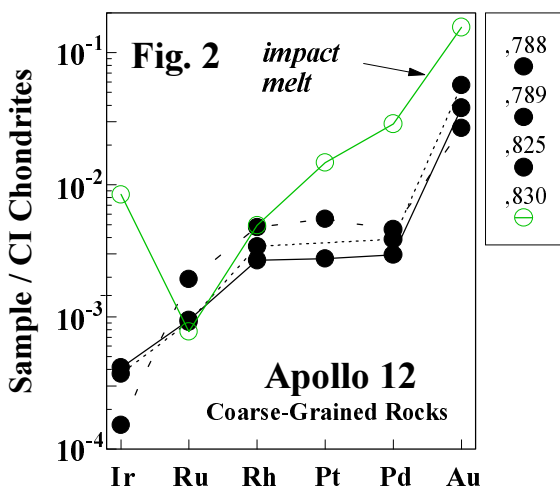
Standard reference material (UMT-1) is routinely and liberally interspersed throughout the run sequence in order to check for reproducibility (Table 1). Internal standards for Rb, Y, La, Lu, and U were used, as these elute from columns well after the PGEs and Au.

Memory effects of previous samples/standards were re- moved using a four-stage wash procedure: (1) 120 sec of 1N aqua regia to strip the tubing and USN spray chamber of lingering elements; (2) 90 sec of 10% HCl for continued cleaning and to equilibrate the system with the HCl matrix; (3) 90 sec of 5% HCl; (4) 90 sec of 5% HCl. The final two washes allow the system to equilibrate with the routine 5% HCl matrix while allowing for the continued rinsing of the system. The four-stage wash procedure also eliminates any build up of residual PGEs and Au in the wash solutions caused by drops adhering to the autosampler probe. Memory effects were monitored by analyzing blank solutions between samples, standards, etc. throughout the run sequence. Further details of the method are found in O'Neill [4] and O'Neill et al. [5].

Table 1: PGE, Au (ppb)* in >1mm 12001						
Soil Fragments & Standards						
Sub-S.	Ru	Rh	Pd	Ir	Pt	Au
Certified UMT-1 Standard						
10.9(1.5)	9.5(1.5)	106(3)	8.8(0.6)	129(5)	48(2)	
Analyses of UMT-1 (n = 5)						
14.3(1.0)	10.9(1.4)	119(4)	7.1(0.5)	123(18)	23.5(2.9)	
Measured Detection Limits (fg/g)						
238	72	594	48	238	594	
Reagent Blank (pg/g)						
bdl#	0.7	bdl	bdl	7	1.3	
Coarse-Grained "Highlands"						
.788	0.67(0.08)	0.36(0.09)	1.65(0.16)	0.19(0.03)	2.7(0.7)	5.5(0.7)
.789	0.65(0.07)	0.46(0.05)	2.17(0.17)	0.17(0.06)	-----	8.2(0.7)
.825	1.4(0.3)	0.64(0.04)	2.57(0.12)	0.07(0.02)	5.5(0.4)	3.9(0.5)
Pigeonite Basalts						
.826	0.41(0.06)	0.16(0.04)	1.51(0.12)	0.29(0.04)	6.1(0.4)	4.3(0.5)
.827	0.29(0.04)	0.17(0.02)	1.2(0.11)	4.93(0.05)	-----	7.5(0.3)
Ilmenite Basalts						
.828	0.48(0.14)	0.28(0.09)	2.13(0.55)	2.97(0.11)	7.2(0.5)	5.1(0.3)
.829	0.70(0.06)	0.55(0.04)	3.63(0.23)	0.19(0.03)	1.84(0.28)	4.5(0.5)
Impact Melt						
.830	0.55(0.03)	0.66(0.03)	16.18(0.12)	3.89(0.08)	14.5(0.3)	22.4(0.4)

*2-sigma errors in parentheses.
#bdl = below detection limits.

PLATINUM-GROUP ELEMENTS AND Au IN LUNAR ROCKS -- A total of eight rocks were analyzed for a suite of five PGE and Au (Table 1) and are plotted in Figs. 1 and 2 relative to chondritic abundances. Based upon mineral chemistry, these samples have been classified as coarse-grained, presumably "highlands" rocks (3), pigeonite basalts (2), ilmenite basalts (2), and an impact melt [6,7]. All samples are depleted in the PGE relative to CI chondrites, from 2 to 4 orders of magnitude. Significantly, the impact melt (**,830**) has Pt and Au abundances a factor of 3-8 higher than all other lunar samples (Fig. 2; open circle), and the other samples, whether of coarse-grained "highlands" (filled circles on Fig. 2) or basaltic affinity, have uniformly low abundances (Pd = 2 to 3.63 ppb; Au = 3.9 to 8.2 ppb). Furthermore, the impact melt exhibits a uniform slope, not evident in the other samples, from Ru to Au. Pigeonite basalts (patterned circles on Fig. 1) have the lowest abundances of Ru, Rh, and Pd; ilmenite basalts (filled squares on Fig. 1) have higher abundances and overlap those of the coarse-grained rocks for these elements.



Samples can be split into two groups on the basis of Ir abundances (0.07 to 0.29 ppb and 2.97 to 4.93 ppb). Those which have Ir abundances > 2 ppb strongly suggest a significant meteoritic component, although evidence of this is not seen either texturally or mineralogically [6,7]. Those samples with relatively low Ir values are thought to be devoid of meteoritic contamination and thus, are considered pristine: highlands clasts **,788**, **,789**, **,825** and mare basalts **,826** (pigeonite) and **,829** (ilmenite).

DEFINITION OF CHEMICAL PRISTINITY -- Warren and Wasson [1] presented several criteria for establishing the pristinity of lunar rocks. These criteria included three strictly geochemical parameters: (1) low siderophile-element contents ($< 3 \times 10^{-4} \times$ CI chondrites; in practice, often only Ir was analyzed); (2) low incompatible-element contents ($< 5 \times 10^{-3} \times$ KREEP levels); and (3) low initial $^{87}\text{Sr}/^{86}\text{Sr}$ (< 0.6992). We have not evaluated parameter (3), but we can evaluate parameters (1) and (2) using data presented here and in Snyder et al. [8,9].

We have previously determined those 1-4-mm fragments from soil 12001 that are petrographically pristine [6,7]. Only one fragment analyzed in this study (impact melt **,830**) was determined to be non-pristine on the basis of petrographic analysis. Indeed, this sample does have an Ir abundance $> 3 \times 10^{-4} \times$ CI chondrites (Fig. 2; open circle). Two other samples (**,827** and **,828**) have demonstrably elevated Ir values and, although "petrographically pristine", cannot be considered chemically pristine (Fig. 1).

Although sample **,826** has an Ir value that is 5×10^{-4} , and, *sensu stricto*, should be considered non-pristine [1], we consider this sample to be pristine. Making use of technological advances over the last decade, we have developed a more precise method of PGE and Au analysis in lunar rocks. Although more data is needed to definitely determine the pristinity cut-off, we suggest from this limited data set that Ir abundances $< 10^{-3} \times$ CI chondrites should be considered part of the original rock and not due to meteoritic contamination.

All of the "highlands" rocks analyzed have incompatible-element contents in excess of $5 \times 10^{-3} \times$ KREEP values (i.e., 110 ppm La, 22 ppm Rb [10]). However, none of the incompatible element values for these samples are $> 10^{-1} \times$ CI chondrites and many are $< 5 \times 10^{-2} \times$ CI chondrites ([9]; Table 1). Therefore, we consider this criteria ($< 10^{-1} \times$ KREEP values) to be a more appropriate cut-off for possibly pristine highlands rocks; however, we concur with Warren [11] that the siderophile-element criterion is a more definitive indicator of pristinity.

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